

11.0 Concluding Remarks and Recommendations

In this section a concluding view on the overall field test experience is provided and recommendations are offered. Although the complexity of driving-related observations tempts one to list a great array of salient details, the attempt here is to take the most high-level view on what transpired. In the sense of a conclusion, we offer what we call the “central finding” followed by a simple summary of its main elements. The recommendations are intended to highlight research initiatives that will help ensure that ACC products and their potential derivatives turn out to be safe and satisfying in the hands of the public.

11.1 The Central Finding

ACC control is remarkably attractive to most drivers.

Because ACC is so pleasing, people tend to utilize it over a broad range of conditions and to adopt tactics that prolong the time span of each continuous engagement. Notwithstanding some concerns, field test subjects were completely successful at operating ACC over some 35,000 miles of system engagement.

One also observes that the role played by the driver as the “supervisor” of ACC control entails some subtle issues whose long-term safety and traffic impacts are unknown.

Thus ACC does not fit a “business as usual” outlook for either the auto industry or for highway operations. The “shared-control” nature of ACC requires a fine match to the perceptual and cognitive behavior of drivers, in a safety-central task that may affect others driving nearby. While offering great promise for improving the quality of the driving experience, ACC implies an inherent necessity for human-centered design.

The following summarizes the basis for the central finding:

1. The strong attraction of ACC seems to be explained by:
 - complete relief of the “throttle stress” that is believed to impose a palpable burden on manual driving
 - great relief of the “headway stress” believed to be embedded within the manual driving task due to human visual limitations in perceiving range and relative velocity to the vehicle ahead

- substantial relief from the frequency of interruption normally required under conventional cruise control
2. These relief mechanisms prevail only when the driver “lets ACC do it.”
 3. Certain observations confirm that people are rather strongly disposed to let ACC do it, namely:
 - high rates of ACC utilization that accrue over a broader range of speeds and road types than with CCC, thus posing a more complex environment within which the driver must judge when to manually interrupt system control
 - participant evaluations that indicated a high preference for the ACC mode of control across many different driving environments
 - a reluctance to even partially intervene upon ACC control by manually applying the throttle when re-accelerating back up to the set speed—even though most drivers clearly detected the need for such partial involvement when operating this ACC vehicle
 - stronger braking levels when ACC disengagement does occur, and at shorter times-to-collision (apparently since drivers delay a braking intervention in order to let ACC handle the conflict, if it can)
 4. The driver’s ability to retain a vigilant, cautious driving style when in ACC engagement is questioned by such observations as:
 - mixed responses among test subjects to certain debriefing questions, including some concern for overconfidence, divided visual attention, and incomplete understanding of the ACC response, at times
 - personalized anecdotes suggesting inattention to the full scope of the normal vigilance task, apparently due to the inadvertent reductive assumption that the ACC deceleration cue serves as a general- (rather than limited-) purpose alert that a conflict is developing ahead

11.2 Recommendations

Recommendations are made spanning five areas of activity, as follows:

11.2.1 On Studying the Collected FOT Data Further

The compiled archive of data from this field test is believed to be unique in the world in 1998. Noting that so many fundamental driving variables are addressable via relational database tools, much additional research can be meaningfully pursued using this resource. Investigations could serve to:

- better underpin standards for ACC and forward-crash-warning (FCW) systems, using the database as a source of quantitative information for addressing issues of concern to SAE and ISO committees
- guide ACC and FCW design decisions and/or the projection of benefits and other impacts of broad system usage within an environment of manually-driven vehicles
- advance understanding on the normal driving process. A very broad array of inquiry on manual driving is possible using the collected data. Because the data provide a plausibly representative estimate of distributions covering some 68,000 miles of manual driving, much can be done in understanding driving styles, control tactics, and the seemingly arbitrary individual travel preferences as exhibited across a rich sample of persons, trip-taking, and traffic-induced conflicts and conditions. The authors believe that a sound understanding of normal driving is imperative if driver assistance products are to have a hope of flourishing. Research on the driving process would also do well to build upon the driving theory that has been initiated herein.

11.2.2 On the Need for Fundamental Understanding on Driver Supervision of ACC

Insofar as ACC poses subtle challenges for human performance due to the supervisory role that the driver must assume, research into the psychological dimensions of this machine-supervision task is needed. Principal among these are the cognitive aspects of performance including the means by which self-manifestation by the ACC system induces a mental model of system function in the mind of the driver. Ultimately at issue is the definition of features that should be embedded within ACC design for limiting the risks of irrecoverable mistakes in the supervision of the system, over a diverse population of drivers. Note that among these issues is the heretofore untouched question of ACC control by the altogether naive driver — that is, the first-time user who just climbs into the car and starts pushing buttons that invoke ACC control.

11.2.3 On the Need for Direct Measurement of ACC's Energy Impact

Since this field test has served to define the utilization duty cycle for ACC operation, it should be straightforward to conduct a controlled experiment for quantifying the energy-consumption impact of ACC. One would simply measure fuel consumption over an

exemplar ACC-usage duty cycle comparing against an acknowledged benchmark cycle for manual driving.

11.2.4 On the Need to Explore the Traffic Impacts of ACC in Greater Detail

It is expected that ACC usage, at high levels of penetration into the vehicle population, will have a significant impact on traffic operations. Within this project, no significant analysis was performed for making such projections although it is apparent that 1) lengthened headway times under ACC control may tend to reduce highway capacity, 2) weaving movements on freeways may be impeded by serial strings of ACC vehicles operating near one-second headway times, but 3) the greater consistency of ACC controllers may tame the tendency for traffic flow instabilities. Serious exploration of traffic flow impacts is felt to be a mandatory part of any near-term program of public research on ACC.

11.2.5 On Examining the Naturalistic Use of ACC With Braking

It is recommended that naturalistic testing of braking-assisted ACC proceed at the earliest possible time, recognizing that most ACC products expected for sale in the United States within the next five years will employ electronically-controlled braking, up to approximately 0.20 g's, in contrast to the 0.07g throttle-and-downshift system employed here. This recommendation follows from the gist of the central finding, above, based upon the following hypotheses:

1. Brake-assisted ACC control will be considerably more attractive than the already very attractive system that was tested here (because all of the human-perceived "relief" mechanisms cited above will be even more fully and consistently realized when operating a polished version of brake-assisted ACC).
2. When braking is added, the ACC utilization domain will expand substantially beyond that seen in this study. One observes, for example, that a three-fold growth in deceleration authority (from the 0.07g level to that of 0.20g) will dramatically expand the number of conflicts that the ACC controller is capable of resolving. In high-speed freeway settings for example (using for estimation the average deceleration results reported earlier for manual braking) ACC with braking should be able to automatically resolve approximately 98% of the conflicts posed when the preceding vehicle is manually braked, whereas the tested system, at 0.07g's, could only manage about 50% of such conflicts. For the

advanced ACC system, then, it would seem almost certain that ACC utilization would climb from the 75% level measured here to nearly 100% of all freeway travel above 55 mph.

Perhaps much more significantly, the ACC utilization level reported here at 13% for all travel *on arterial streets* in the 30-to-55 mph range might easily rise to 30% or more when driving with a braking-assisted controller. Since surface streets pose a harsher, more complex array of conflicts, and since driver intervention will surely be postponed until deeper into each conflict sequence, (once the driver has learned that the 0.20g controller can handle most of them) the drama of ACC supervision is likely to rise if “local usage” of the system grows as expected. But it may be that drivers tend to realize the increasing risk after a few intervention experiences, such that compensatory strategies of utilization begin to appear. However these crucial issues play themselves out, we believe that minimal information exists in the public domain for predicting the outcomes, at present.

3. Driver vigilance and attentiveness to the full scope of potential driving hazards may be lower when operating a brake-assisted ACC controller compared with the low-authority system examined here. Since the ability to sense the onset of deceleration in the field-test cars was nearly universal across test subjects, minimal further benefit from the deceleration cue is expected to derive from any higher-g range of ACC control authority. On the other hand, even the simplest model of learning would imply that drivers will tend to gain greater confidence in a system that readily manages almost every headway conflict that comes along. Given the predominance of headway as a conflict mechanism calling for vigilance in all normal driving, a very high level of comfort with ACC control may cultivate the odd tendency in some persons to mentally underestimate the domain of all attentional demands, reducing it occasionally to that of the headway modality, alone.

If and when this occurs, attention may be allocated to less than the complete space over which visual surveillance is needed for safe driving. That is, the driver may more frequently devote visual attention to other interests either inside or outside of the vehicle while implicitly relying on ACC deceleration as some kind of general-purpose alerting mechanism (which it is not). European research reporting an unexplained inattention to traffic lights, when operating ACC on surface streets, may also be linked to the same hypothesized quirk in cognitive behavior.

11.3 Concluding Comment

The suggestions for further research, listed above, have tended to focus on concerns that may or may not turn out to significantly challenge the development of fully acceptable ACC products. Putting such concerns in perspective, the authors must acknowledge that certain technology leaders in the auto industry have been studying ACC for almost fifteen years, presumably gaining proprietary knowledge that has resolved some issues through designed features of the system or has proven others to be insignificant. Indeed, the rapid pace of ACC marketing plans suggests the conviction within several OEM companies, especially those headquartered outside of the United States, that ACC will succeed as a popular automotive feature that appeals to almost any driver.

In considering safety concerns, we must also acknowledge the remarkable adaptability of the human operator who brings a primordial ability to manage risk while maximizing personal benefit, when the task is understood. Further, the few cautionary notes that question whether high-fidelity adaptation to ACC will be assured constitute rather tenuous observations within the overwhelmingly positive bulk of results produced here. Thus, the reader is asked to consider such cautions as a call for a fuller understanding that will guarantee the eventual success of ACC products in the hands of a driving population that will probably use them in the majority of all miles driven.